

ENTROPY AND CAVE ANIMALS

DAVID W. DEAMER

Department of Physiological Chemistry, The Ohio State University, Columbus 10

The lack of eyes and pigment which occurs in many species of cave animals is widely distributed; sightless and non-pigmented species occur in every phylum represented in caves. The partial listing below gives some idea of the generality of this phenomenon:

Fish	<i>Amblyopsis speleus</i>
Salamander	<i>Haideotriton wallacei</i>
Snail	<i>Antroselates spiralis</i>
Flatworm	<i>Dendrocoelum percaecum</i>
Crayfish	<i>Orconectes pellucidus</i>
Shrimp	<i>Palaemonias ganteri</i>
Isopod	<i>Asellus pricei</i>
Amphipod	<i>Eucrangonyx flagellatus</i>
Beetle	<i>Neaphaenops tellkampfi</i>
Collembola	<i>Entomobrya cavicola</i>
Thysanura	<i>Campodea cookei</i>
Harvestmen	<i>Phalangodes armata</i>
Millipede	<i>Scoterpes copei</i>
Spider	<i>Anthiobia monmouthia</i>

It is generally accepted that these animals are descendants of eyed and pigmented ancestors. Since this trait is so widespread among cave animals, any explanation of its evolutionary mechanism must also account for its ubiquitous occurrence. A number of hypotheses have been offered but it remains something of a problem for Darwinian theory.

Strictly on the basis of natural selection, the Darwinist might say that if cave-adapted animals did indeed evolve from eyed and pigmented ancestors, then blindness and lack of pigment are positive survival traits in caves. Rhoades (1962) for instance, proposed that cave crayfish somehow use less energy as a result of their condition and are thus better fitted for survival. In terms of an animal's total energy turnover, however, the amount necessary for producing eyes or pigment would seem insignificant. To carry the argument further, if very small decreases in energy expenditure did have positive survival value in caves, it would seem likely that evolutionary processes would produce cave animals which are miniaturized versions of corresponding species aboveground. However, in my experience the size ranges are not drastically different.

Vandel (1961), working at the subterranean laboratory at Moulis, France, found that the larval stage of a local blind cave salamander has eyes and pigment which disappear with maturity. He suggested that this may be a hormonal effect involving a hyperthyroid state induced by the absence of light, but this is a specific biochemical mechanism and still does not elucidate the more general problem even if correct.

A third explanation is that when a species first managed to live in caves, eyes and pigment were unnecessary for survival and any mutations toward lesser visual acuity and pigment caused no loss of survival potential. These mutations slowly diluted the original stock, finally reaching the point we see today. This seems reasonable, as far as it goes, but lacks a clear-cut driving force such as we have in natural selection.

The purpose of the present paper is to propose a possible "force" which would

tend to direct evolution toward simplification when an environmental factor is completely absent, as light is to the cave animal. This proposition may be stated as follows: that disuse of a complex organ or system through lack of natural selection results in its loss due to gene entropy tending to approach a maximum.

Entropy is an important physical concept, being a function of temperature and heat content of a system in relation to its environment. When energy is derived from the system, its entropy change is positive and is a measure of the energy unavoidably lost in the process due to random thermal activity. The concept of entropy, however, has been found to have much broader application; it is in this larger sense that it is used here. More generally speaking, entropy is a measure of the degree of disorder in any system. The more disordered a system, the greater its entropy and vice versa.

Information content can also be thought of in terms of entropy, since information has order. To make a crude analogy, a ten word sentence can be considered to have a certain information content. Using this information, a reader can grasp the meaning of the sentence. However, if the words are shuffled randomly, some information is lost. The reader can still understand the words but no longer finds any meaning in their order. If the letters themselves are shuffled there is an even greater loss of information and the original meaning is irretrievably lost. The entropy of the system has increased.

The genetic code is actually a form of information. For a gene to be meaningful in terms of the system it produces in the developing animal it is believed that the base pairs of DNA comprising the gene must be in a certain order. Changes in this order through mutation are analogous to the random shuffling of words or letters in the ten word sentence mentioned above.

Entropy is defined such that any system proceeds to the maximum entropy possible for it, that is, the greatest amount of randomness. Unless energy is put into a system in some manner, any order (or information) the system has will gradually become more and more randomized.

Therefore, as a working hypothesis it is proposed that the genetic make-up responsible for the production of an eye or pigment contains more information than the genetic make-up which does not produce these characters. (It must be realized that we are speaking here of very complicated structures which probably take the information of hundreds of genes to produce and maintain, and not just simple characters such as eye color or melanin pattern.)

Above-ground, information has been "impressed" into the genetic make-up of animals by natural selection of those fittest to survive, in this case, mutations tending toward production of eyes and pigmentation. When these animals found themselves in forming caves many thousands of years ago and managed to survive, eyes and pigment were no longer useful in the environment of absolute darkness. There were no selective processes going on to preserve strains with vision and pigment. Therefore, randomization of the genetic information could occur through mutation without destroying the survival potential of the species and naturally the system would proceed to the maximum entropy possible. This would result in totally eyeless and unpigmented species of animals.

Using the above hypothesis, several predictions can be made. First, the degradative process would necessarily be a gradual one, and unless a species had inhabited a cave for quite some time, intermediate stages should be seen. As a matter of fact, the cave tetra from San Luis Potosi, Mexico, shows a four step gradation from eyed and pigmented to completely blind and white (Woods, 1956).

Secondly, every system which had some relation to light energy on the surface would atrophy in that capacity in the cave animal. So far, only eyes and pigment have been mentioned. There are more subtle relations which might be studied, for instance, vitamin A metabolism and enzyme systems which normally produce melanin.

A third approach would involve surface factors other than light which are lacking in the cave environment. Any complex organ or system which had evolved in response to such surface stimuli would degenerate in the cave animal. Thus, adjustment mechanisms and behavior which specifically protect the surface animal against fluctuating temperatures should be lost in the cave animal, since underground temperatures are nearly constant. Also, sound vibrations, though possible, are rare occurrences and probably can serve no useful purpose. Therefore, any sensory apparatus for detecting sound should be lost. Woods (1956) has mentioned the insensitivity of cave fish to loud noises and I have made similar observations with both fish and crayfish.

In summary, chance mutations in genes associated with complex light-related systems tend toward simplification in cave animals. It is proposed that the driving "force" is a function of an increasing entropy in the genetic information which governs production of eyes and pigment, rather than Darwinian selective processes

LITERATURE CITED

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